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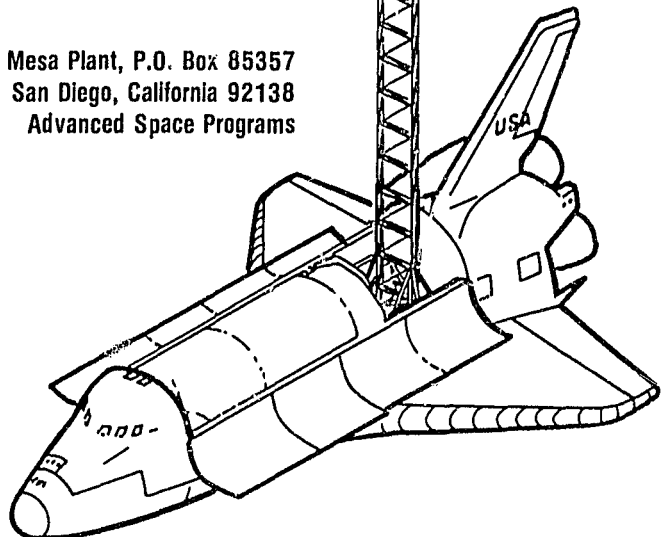
SPACE CONSTRUCTION EXPERIMENT DEFINITION STUDY (SCEDS) PART III

FINAL REPORT VOLUME I • EXECUTIVE SUMMARY

CONTRACT NO. NAS9-16303

GENERAL DYNAMICS
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Advanced Space Programs



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SPACE CONSTRUCTION EXPERIMENT DEFINITION STUDY (SCEDS) PART III

FINAL REPORT VOLUME I • EXECUTIVE SUMMARY

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Houston, Texas 77058

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FOREWORD

The final report was prepared by General Dynamics Convair Division for NASA/JSC in accordance with Contract NAS9-1603, DRL No. T-346, DRD No. MA-664T, Line Item No. 3. It consists of two volumes: (I) a brief Executive Summary and (II) a comprehensive set of Study Results.

General Dynamics Convair personnel who significantly contributed to the Part III study include:

Study Manager	John Bodle, Andy Robertson
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Preliminary Design	Chuck Lungerhausen
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The study was conducted in Convair's Advanced Space Programs Department, directed by D. E. Charhut. The NASA/JSC COR is Lyle Jenkins of the Program Development Office.

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SECTION 1

INTRODUCTION

1.1 SCOPE

This is the first of two volumes comprising the SCEDs Final Report. It provides an executive summary of the study results. Volume II contains the detail results of all Part III study results. This report is the final deliverable contract data item.

1.2 STUDY OVERVIEW

1.2.1 PART I SUMMARY. The Part I study tasks focused on the definition of a baseline Space Construction Experiment (SCE) concept, shown in Figure 1-1 and concepts for additional suitcase experiments for Extravehicular Activity (EVA) and Remote Manipulator System (RMS) construction operations.

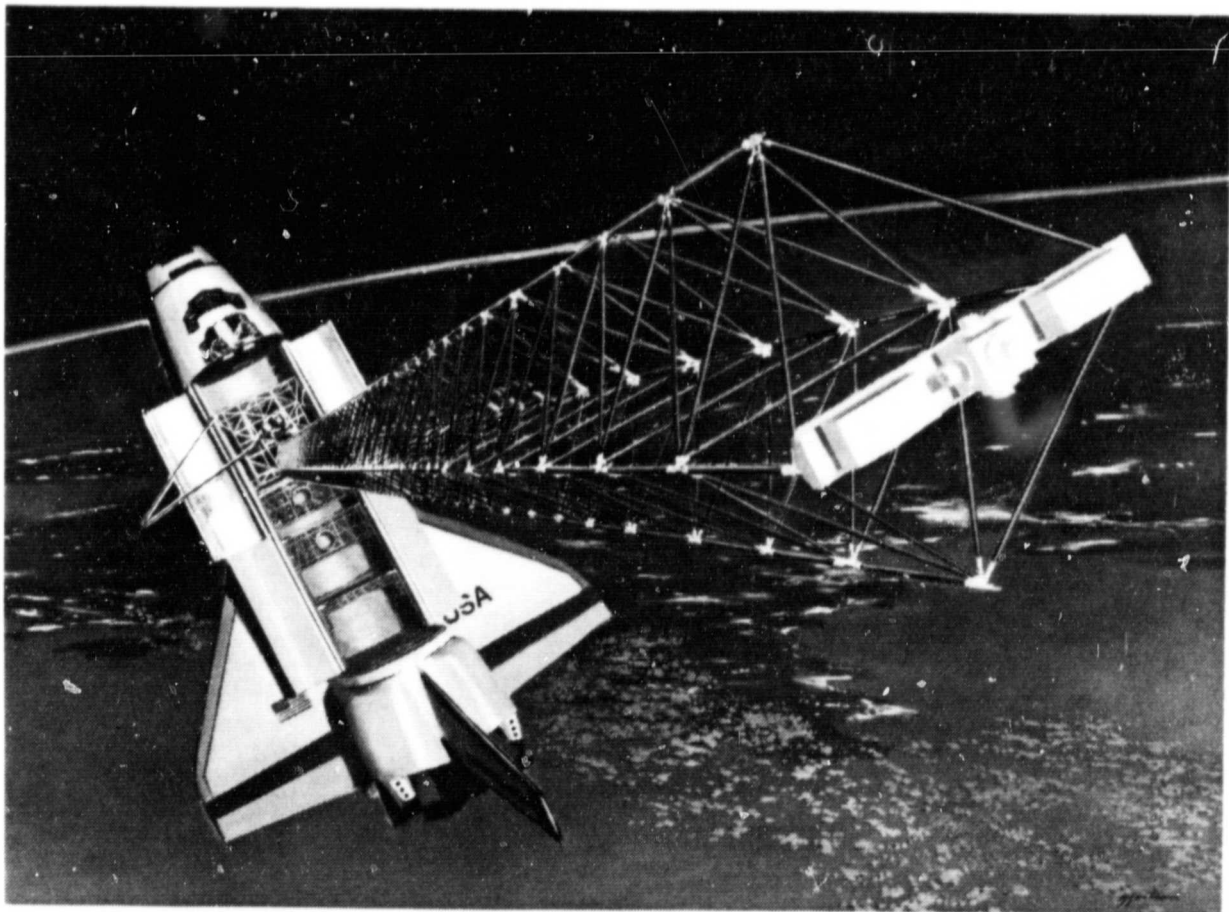


Figure 1-1. Baseline Flight Experiment Concept

The baseline structure is a tetrahedral diamond cross-section truss beam having a very low coefficient of thermal expansion, achievable through the use of graphite composite materials for construction. Structural dynamic tests will provide data to be correlated with math model predictions. Minimal ground testing is to be performed, and minimum flight instrumentation employed.

The experiment is to remain attached to the Orbiter throughout the test. Jettison capability is provided; however, the experiment will normally be automatically retracted, restowed, and returned to earth by the Orbiter.

A variety of appropriate Large Space System (LSS) construction and assembly operations utilizing basic Space Transportation System (STS) capabilities (EVA, RMS, CCTV, Illumination, etc,) were to be conducted and correlated with ground tests and simulations.

1.2.2 PART II SUMMARY. After the conclusion of Part I, the study objectives were expanded by NASA JSC and NASA LaRC to place greater emphasis on the structural dynamics and controls technology aspects of the experiments and to specifically design the experiment to develop and demonstrate the technologies to meet requirements for large space antenna feed masts. The objectives continued to stress the development of Orbiter capabilities necessary to support large space structures construction operations, including the ability to maneuver and control large attached structures and to perform in-space deployment and construction operations.

The Part II study activities were divided into the following major tasks. Further development and definition of the SCE for integration into the Space Shuttle. This included development of flight assignment data, revision and update of preliminary mission timelines and test plans, analysis of flight safety issues, and definition of ground operations scenarios.

Convair also provided revised SCE structural dynamic characteristics to the Charles Stark Draper Laboratory for simulation and analysis of experimental tests to define and verify control limits and interactions effects between the SCE and the Orbiter Digital Automatic Pilot (DAP).

1.2.3 PART III SUMMARY. The Part III study tasks were directed toward definition of an early shuttle controls and dynamics flight experiment, as well as evolutionary or supplemental experiments, that will address the needs of the dynamics and controls community and demonstrate the shuttle system capability to perform construction operations. The requirement to experimentally evaluate shuttle digital autopilot (DAP) interactions was dropped for Phase III. A new requirement that the first bending mode of the SCE be above 0.15 Hertz to avoid coupling with the DAP was adopted.

The level of definition of the first flight experiment is to be in sufficient detail required for NASA to prepare for competitive procurement. Also the planned availability of the NASA, LaRC

developed Space Technology Experiments Platform (STEP) provided a resource that could be effectively utilized as part of the proposed experiment. Integration of the experiment with STEP was accomplished during the Phase III study.

The major objectives of Phase III were to:

- Propose and define an extended controls and dynamics flight research program using the Part II test article.
- Propose and define enhanced test configurations for follow-on flight research
- Establish needs for and benefits of flight research objectives
- Integrate test article with the Space Technology Experiments platform (STEP)
- Revise and update mission timelines, preliminary test plan and the preliminary program plan (including cost estimates and the schedule)

All objectives were satisfied and the results are presented in detail in the subsequent sections of this report.

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SECTION 2

STUDY RESULTS

Study results of SCEDS Part III are summarized in the following subsections. These include experiment objectives analysis, dynamics and instrumentation analysis, test plan and programmatics.

2.1 EXPERIMENT OBJECTIVES ANALYSIS

To establish an experiment series which is responsive to the needs of the technical community, an analysis of possible experiment objectives was conducted. Two complementary approaches were used to evaluate objectives for the flight experiment. First, technology needs were identified and ranked from a project manager's standpoint. As a separate effort, research areas were identified on the level of interest of the individual discipline engineer.

2.1.1 TECHNOLOGY NEEDS EVALUATION. The technology needs were identified and then rated on importance to each of three mission classes: Space Station, Land Mobile Satellite System (LMSS), and Optical/Laser. These categories were treated as classes and not as specific configurations. Thus "LMSS" indicates any mission using large space structure with pointing requirements in fractions of a degree, a potential shape maintenance problem, and important structural modes below 1.0 Hertz. Since these mission classes have different requirements, the technology needs usually have different degrees of importance in each case. Numerical ratings from 0 to 10 were assigned to the technology needs based on the criteria:

- 0 for no application to mission
- 10 when absolutely required

The numerical results were weighted to emphasize near-term missions and degree of NASA interest:

- x3 for space station
- x2 for LMSS
- x1 for optical/laser

Thus, although space-borne large lasers present some very interesting and challenging problems, that mission class was given a low weighting. The technology needs were ranked and grouped into three categories (A, B and C). Category A consists of those needs which were assigned the highest priority.

Before relating the needs to a specific experiment, the various possible MAST configurations were reviewed. The configurations are shown in Figure 2-1. Configuration I is the fully instrumented straight structure with control actuators at the tip only. These tip actuators can be used as exciters or in a simple local velocity

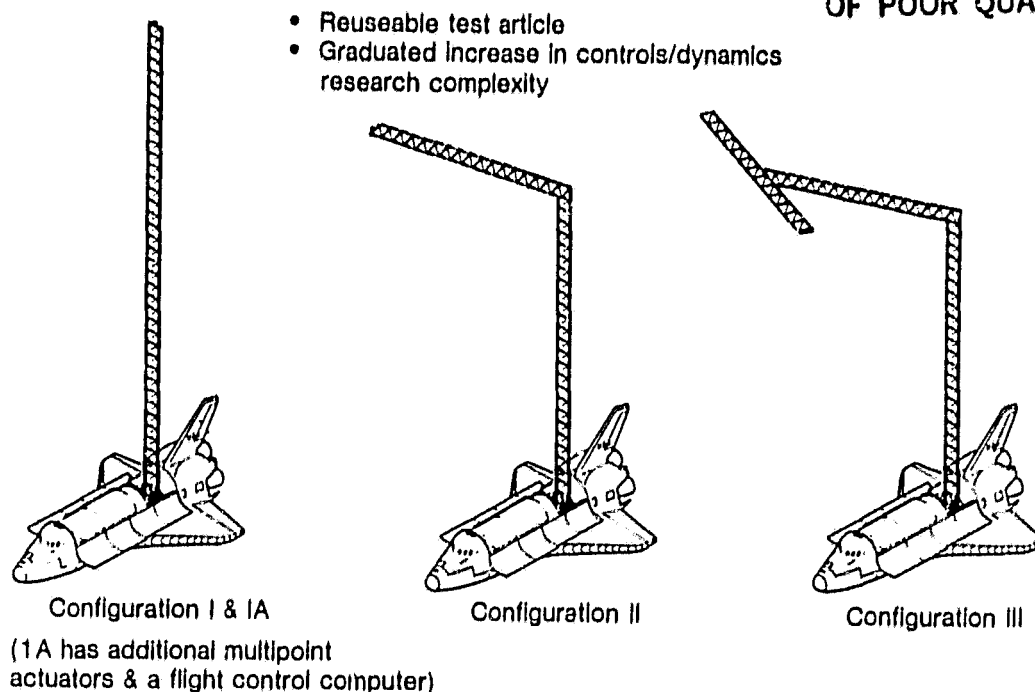
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Figure 2-1. MAST Configurations

feedback (LVFB) mode which does not require a digital computer. Configuration IA has additional actuators and a digital computer so as to provide for a greater variety of control techniques. Configuration II uses an actuator to rotate the top section of the structure so as to add significant yaw modes. A crosspiece is added to Configuration II to form Configuration III which is expected to have the most complex set of modes in all three axes. The crosspiece rotating on the bent section should approximate the characteristics of an antenna dish on a support arm.

The ranking of the technology needs and the capability of the various configurations to address the technology needs is shown in Table 2-1.

2.1.2 RESEARCH AREAS. An independent approach to identifying experiment objectives was taken by having a technical specialist assemble an exhaustive list of research areas of interest to controls and structural dynamics for large space systems.

These issues were summarized to a more compact form and compared with the Technology needs of Table 2-1. The ability of the various configurations to address the Research issues was also evaluated. Table 2-2 presents the results. It can be seen that all of the research areas can be related to a technology need. Further, the ability of the various configurations to address the issues is the same as it was for the technology needs: Configuration I addresses a significant portion of the issues, the more complex configurations address most of the issues, and further expansion could address all of the issues except agile systems.

Table 2-1. Technology Needs Addressed by MAST Configurations

	Requirement addressed by configuration			
	I	IA	II	III
CATEGORY A: HIGHEST PRIORITY				
A1 — Actuators & sensors for active damping & vibration control	✓	✓	✓	✓
A2 — Robust control systems which do not require an exact knowledge of the structural dynamics	✓	✓	✓	✓
A3 — Techniques for the control of large flexible space systems		✓	✓	✓
A4 — Techniques for the control & stabilization of orbiter-attached flexible structure		✓	✓	✓
A5 — Knowledge of potential structural modeling errors in large space structure	✓	✓	✓	✓
A6 — Techniques to model & analyze deployment & retraction dynamics	✓	✓	✓	✓
CATEGORY B: SECOND PRIORITY				
B1 — Control techniques to avoid adverse interactions between dynamic systems (rigid body pointing & stabilization, active structural damping, and/or shape control)		✓	✓	✓
B2 — Control techniques to tolerate changes in structural geometry (step and/or continuous)	✓	✓	✓	✓
B3 — Techniques to enhance structural models by ground testing structural subsections	✓	✓	✓	✓
B4 — Confirmation of the LSS disturbance environment & definition of the resulting structural motions	✓	✓	✓	✓
B5 — Techniques for the control of structure during deployment and/or assembly	✓	✓	✓	✓
CATEGORY C: THIRD PRIORITY				
C1 — Actuators & sensors for shape controls		•	•	•
C2 — Techniques to isolate severe vibration sources		•	•	•
C3 — Techniques for the measurement & control of the shape of large antennas or optical systems		•	•	•
C4 — Techniques for in-orbit identification of the structural model		✓	✓	✓
C5 — Definition of the role of passive damping		•	•	•
C6 — Techniques to fix up very "soft" structure with active control				
C7 — Techniques to rapidly slew & point agile LSS				

✓ Addressed • Could be addressed by further expansion

2.2 PRELIMINARY DESIGN AND ANALYSIS

2.2.1 REQUIREMENTS. The structural requirements for the MAST test as established by NASA/LaRC are shown below.

- Compatible with STEP experiment carrier
- Size and stiffness
 - Approximately 2×10^7 N-M²
 - 1.2-1.4 meters depth
- Compaction ratio
 - (deployed length/stowed length) = between 20 and 25
- Test article design to withstand vernier RCS loading in lieu of primary RCS
- 60 meters in length
- Employ high precision beam joints (zero free play)
- Sequentially deployable truss beam
- Lowest natural frequency ≥ 0.15 Hz

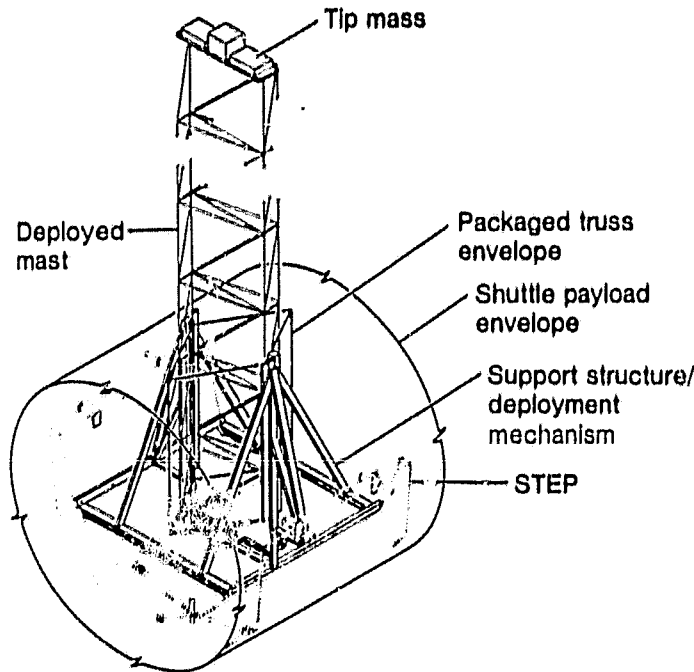
2.2.2 PRELIMINARY DESIGN. The baseline structural test article configuration selected in Parts I and II of the study was the General Dynamics Convair designed deployable tetrahedral truss

Table 2-2. Research Areas Addressed by
MAST Configurations

Technology Need	Addressed by MAST Configuration			
	I	IA	II	III
Modeling				
• Modal uncertainty — Modal behavior	✓	✓	✓	✓
— Structural properties		•	•	•
• Validity of linear models — Nonlinear effects	✓	✓	✓	✓
• Modal synthesis — Validity of modal synthesis techniques	✓	✓	✓	✓
• Continuum modeling — PDE models	✓	✓	✓	✓
— Traveling waves	✓	✓	✓	✓
— Boundary conditions	✓	✓	✓	✓
Systems Identification				
• Open loop ID — Measurement of open loop dynamics	✓	✓	✓	✓
• Closed loop ID — Measurement of closed loop dynamics		✓	✓	✓
• Continuum model ID — Measurement of continuum model dynamics	✓	✓	✓	✓
Dynamics				
• Deployment modeling — Geometric changes	✓	✓	✓	✓
— Mass changes		•	•	•
Control				
• Control algorithm performance — Robustness	✓	✓	✓	✓
— Active damping	✓	✓	✓	✓
— Multipoint control		✓	✓	✓
— Disturbance rejection		✓	✓	✓
— Actuator/sensor placement	✓	✓	✓	✓
• Subsystem interaction — Decentralized control		✓	✓	✓
— Control hierarchy		✓	✓	✓
• Control during geometry change — Deployment control	✓	✓	✓	✓
— Gain scheduling		✓	✓	✓
— Adaptive control		✓	✓	✓
• Static shape control — Shape control algorithm		•	•	•
— Actuators/sensors		•	•	•
• Control system components — Sensors	✓	✓	✓	✓
— Actuators	✓	✓	✓	✓
— Computers		✓	✓	✓
• Continuum control — PDE control		✓	✓	✓
— Traveling waves		✓	✓	✓
• Integrated design — Integrated control mechanism		✓	✓	✓
• Agile systems — Agile systems control		•	•	•
• RCS control — RCS control of flexible structure		•	•	•

✓ Addressed • Could be addressed by further expansion

with a diamond cross section. This remains the baseline configuration although a significant change involved eliminating the carpenter tape hinges. The need to double fold the stowed structure no longer exists and the open diamond structure reduces manufacturing cost (fewer joints) and provides increased flexibility relative to available space for mounting actuators, instrumentation or anything else that more complex configurations might require. Other changes involved revisions to the support structure to ensure compatibility with STEP. The revised SCE concept is shown in Figure 2-2.



The support structure is made up of two aluminum box beams in the longitudinal direction joined to two aluminum I-beams in the transverse direction. The roll frames are joined to the longitudinal box beams and deployment structure while the pitch frames are joined to the I-beams and the deployment structure. This forms an open rectangular structure divided by the deployment structure and provides easy access to electronics packages mounted on the STEP pallet. The entire structure is tied to the STEP pallet at eight hard points with pyrotechnic separation nuts should jettison of the experiment become necessary.

Figure 2-2. Revised Space Construction Experiment (SCE) Concept

The revised truss structure, shown in Figure 2-3 has a packing or compaction ratio of 22:1 and has three differ-

ent types of joints, the carpenter hinge having been eliminated. Four configurations have been examined to ensure they can be packaged individually on a single STEP pallet. Configuration I is a simple straight deployable beam intended for the first flight. Configurations IA, II and III are relatively simple follow-on concepts intended to address more complex controls and dynamics issues.

Structurally, Configuration IA is the same as Configuration I. In addition to the control actuator at the tip of the truss, Configuration IA has torque wheel actuators at bays 15, 23 and 29 plus a digital computer to explore multipoint actuation capability.

Configuration II uses a pivot and latch mechanism to articulate a portion of the top of the truss so as to provide significant modes in the yaw axis.

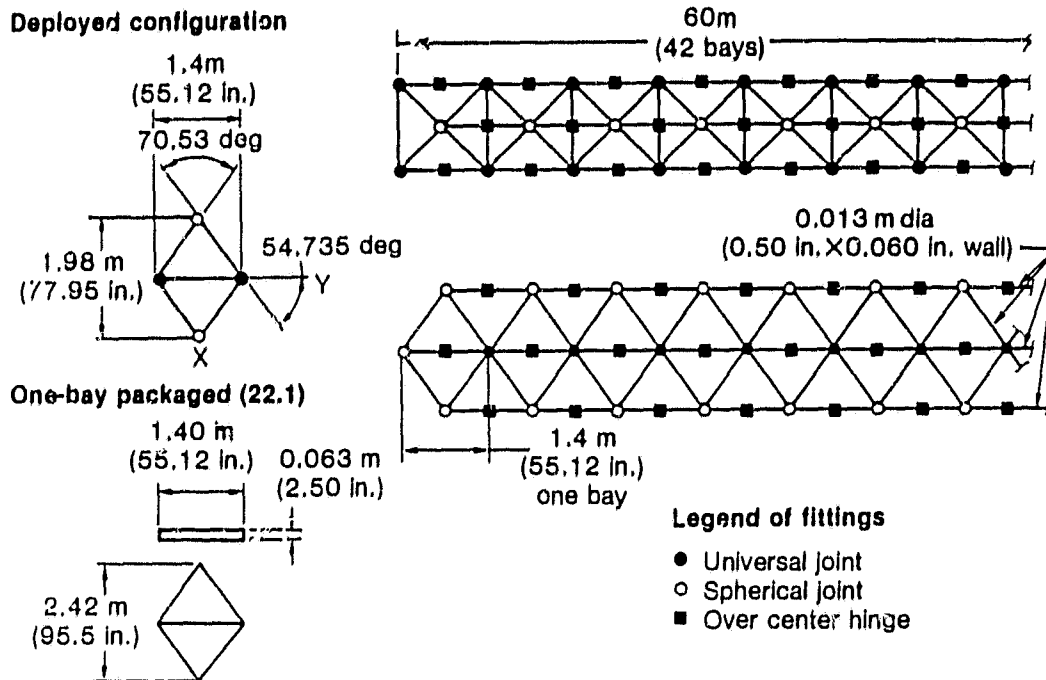


Figure 2-3. Revised Tetrahedral Truss Geometry

Configuration III is shown deployed in Figure 2-4. This is the same as Configuration II with Astromasts that deploy as a cross piece to provide the most complete set of modes in all three axes. This arrangement will exhibit some of the modal behavior of a large antenna dish deployed from a support arm and a feed mast. The ability to package Configuration III within the volume limitation of a single STEP pallet has been verified.

The end of the deployable truss is equipped with a special support frame for the damper sets and tip mass. Six damper sets, each consisting of a torque motor, rotor, and rate gyro sensor are mounted in a housing such that there are two damper sets per axis. Two steel bars are attached to the support frame, each by an explosive bolt. The steel bars provide the added mass necessary to bring the total weight of the tip package to 100 kg. However, the tip masses must be jettisoned to provide a favorable center of gravity of the experiment for payload jettison in the event of a retraction failure of the truss.

2.2.3 CONTROLS AND AVIONICS INTERFACES. The MAST controls are required to perform the functions of:

- a. Carriage advance
- b. Carriage retract
- c. MAST tip torque actuation
- d. MAST tip torque damping
- e. Structural motion sensing
- f. Structural stress sensing

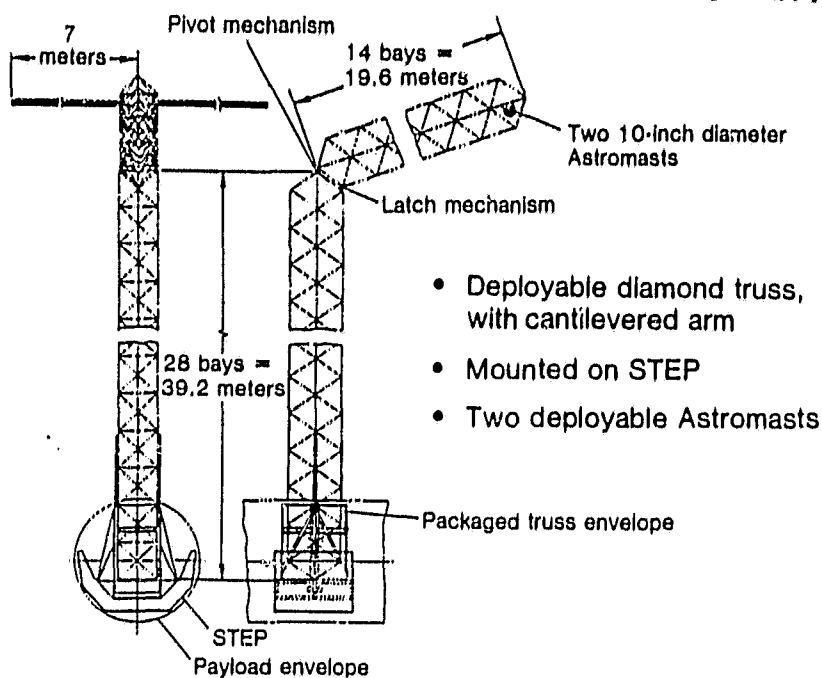


Figure 2-4. SCE - Configuration III

- g. Structural thermal sensing
- h. Power filtering and conversion
- i. Power control
- j. MAST system safety
- k. Expansion capability for follow on advanced structural experimental tests

A fundamental controls philosophy criterion is that the MAST controls avionics shall not mask the basic structural behavior and response. If the MAST structural response is modified by addition of avionics units and cabling, the modified response shall be predictable and the basic structural response shall be extractable from the MAST experimental data. A fringe benefit of modified structural response due to the addition of avionics units and cabling, is the experimental data base available for future provision of avionics on space structures.

An optimum avionics functional partitioning is realized by utilizing the STEP avionics facilities for MAST supervisory control, data management, prime power control, and system safety. The MAST controls avionics provides the MAST carriage operations and experiment control loop functions along with sensor data digitizing.

The MAST controls philosophy utilizes the STEP command and control processor for MAST supervisory control by the mission specialist from the Orbiter aft flight deck (AFD) operator keyboard and display unit.

The STEP data management processor provides the MAST data interrogation and reception via the STEP digital I/O, data processing, formatting, and recording. The STEP data management processor inputs the mission specialist data display, provides the ground data transmission, and makes pertinent data available to the Orbiter avionics and crew via the Orbiter payload data interleaver (PDI).

An extension of the STEP power control is provided by the MAST 28 VDC power switch (located in the STEP power control and distribution box) control by the mission specialist from the AFD Standard Switch Panel (SSP). Remote MAST load switching is controlled from the STEP command and control processor.

In order to reduce the MAST deployment cable flexing, the impact on MAST structure dynamics, and the complexity of harness routing and installation on the structure, hardware interconnections along the MAST structure are minimized by:

- a. Utilizing serial digital control and data busses.
- b. Using self clocking data to eliminate the requirement for a clock bus.
- c. Locating digital bus interface units at convenient truss bays for short run sensor harnessing.
- d. Utilizing remote load power switching on the MAST 28 VDC power bus.

Intelligent digital bus interface units utilizing microprocessor technology provide the required capability and flexibility for bus and sensor/actuator interfaces in a low mass and volume suitable for truss mounting.

The Orbiter and STEP avionics block diagram is presented in Figure 2-5. It was derived from information provided by NASA/LaRC, and from the Space Shuttle System Payload Accommodations, JSC 07700, Vol. XIV.

A very simple avionics physical interface between STEP and MAST has been established (Figure 2-6). It consists of:

- a. A single control bus.
- b. A single data bus.
- c. A 28 VDC supply bus and return.
- d. Activation and return for four electro explosive device bridge wires in two explosive bolts (eight conductors total).

The MAST avionics for Configuration I consists of (Figure 2-6):

- a. The ten BIUs for sensor/actuator interfacing.
- b. A MAST tip torque actuator/damper for MAST experiments.

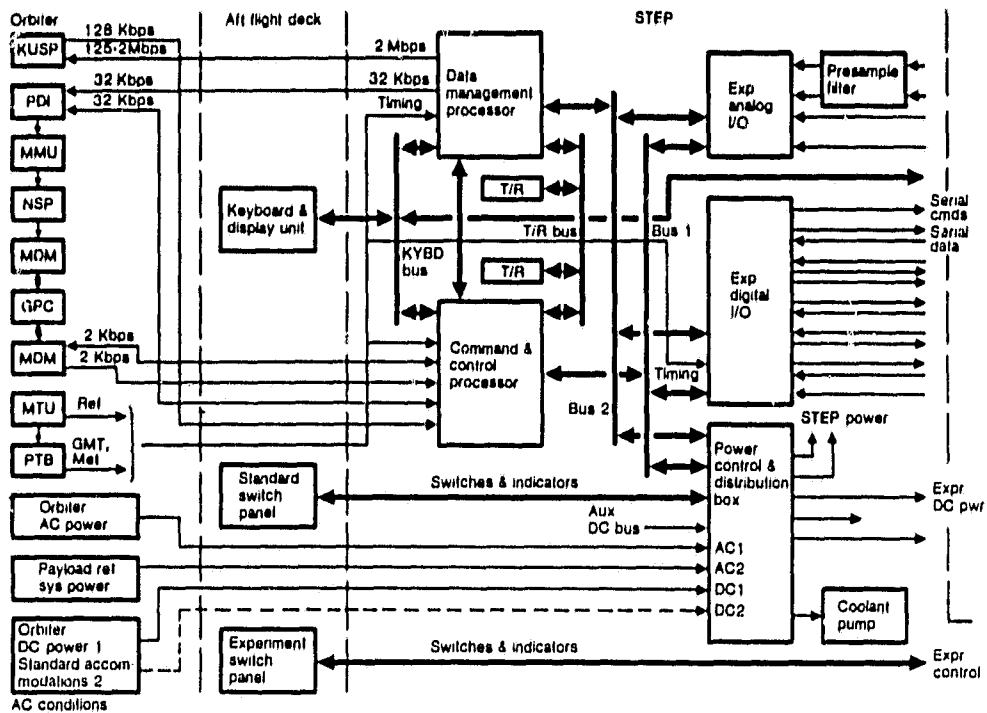


Figure 2-5. STEP/Orbiter Avionics Interface

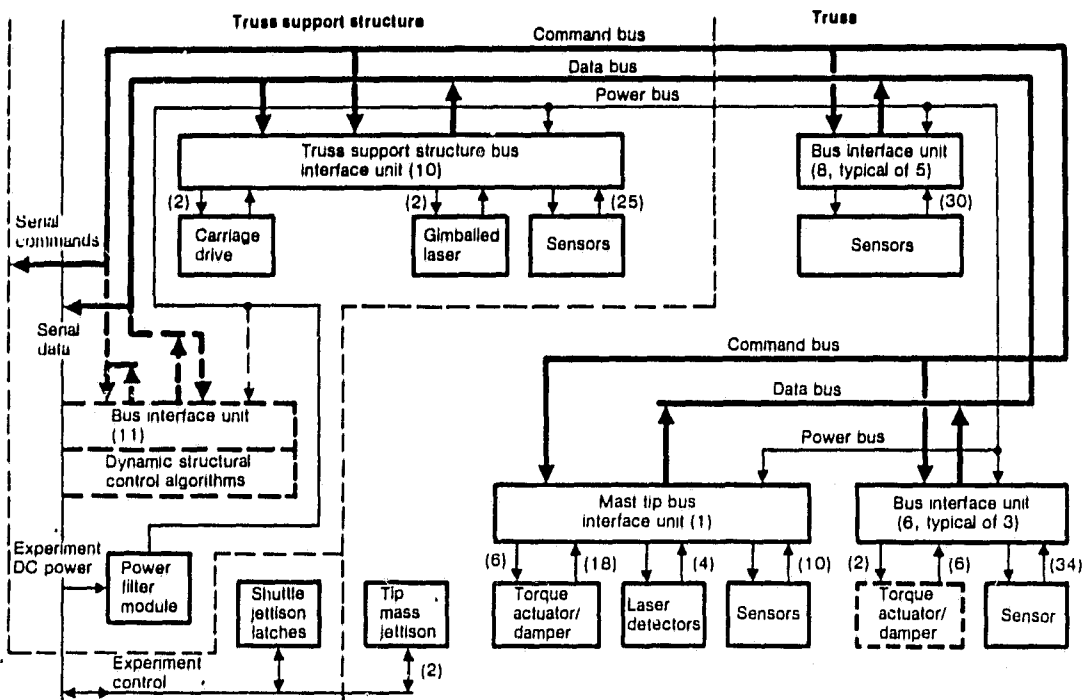


Figure 2-6. STEP/MAST Avionics Interface

- c. Truss structure mounted sensors (thermocouples, strain gauges, accelerometers) for assessing structure performance, and experiment feedback.
- d. Dual rail carriage deployment/retraction redundant drive.
- e. Laser tracker (GFE) for tip deflection and tip longitudinal motion sensing.
- f. Power filter module to suppress STEP/Orbiter generated transients and prevent MAST generated EMI.
- g. Hardware control of redundant tip mass jettison pyro bridge wires.
- h. Control, data, and power busses.
- i. Expansion flexibility for adding three torque actuator/damper sets and dynamic structural control algorithms for MAST Configuration IA, and additional undefined avionics for Configurations II and III.

2.2.4 DESIGN ANALYSIS. Analyses were performed to verify the structural capability of the revised SCE truss and truss support structures. Mass properties were also updated to incorporate the latest configuration data.

Truss loads for the revised truss configuration (see Figure 2-3) with a 100 Kg tip mass and VRCS control moments applied by the Orbiter were determined to be very low, as seen in Figure 2-7. The truss struts are manufactured from GY70/934 graphite epoxy material and are 0.5 inch in diameter with an 0.060 inch wall. Further refinement of the structure would be required to ensure that the experiment

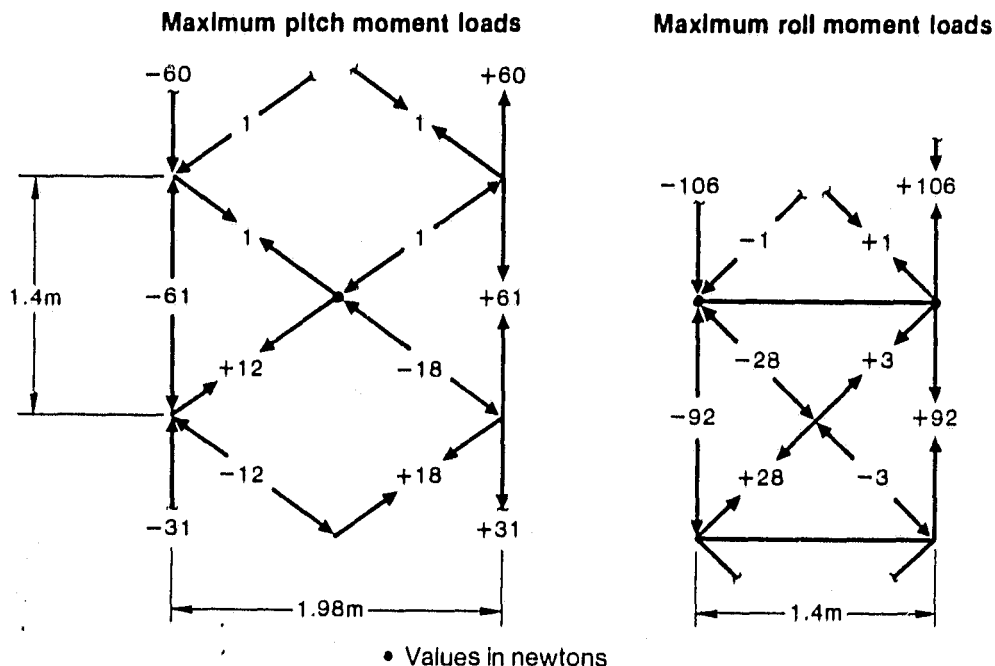


Figure 2-7. Revised Truss Loads

requirements are satisfied with a minimum weight, minimum cost design with an optimal compation ratio.

Deployment rail loads were computed for the new deployable truss configuration with a 100 Kg tip mass. Shear and moment loads applied in pitch and roll were determined for the VRCS "on" case. The maximum loads are summarized in Figure 2-8.

Mass properties for the revised experiment were calculated, see Figure 2-9. The moments of inertia are given relative to the center of mass of the experiment. The center of gravity is shown relative to the Orbiter coordinates. The mass properties of the Orbiter are not included in these tables. The center of gravity for the fully deployed truss with the tip mass ejected is shown for reference.

2.3 DYNAMICS AND INSTRUMENTATION ANALYSIS

2.3.1 FLEXIBLE MODE SUMMARY. The modes of interest are the first five modes in pitch, the first five modes in roll, and any other modes that fall in the frequency band set by the pitch and roll modes. The modes of interest are shown in Table 2-3 and it can be seen that the frequency ranges from 0.190 Hertz for the first roll bending mode to 26.5 Hertz for the fifth pitch bending mode. There are two compression modes and one torsion mode in the frequency band of interest. It might be noted that the first bending mode is above 0.15 Hertz which has been set as the lower allowable limit to avoid adverse coupling with the Digital Autopilot of the Orbiter.

Figure 2-10 shows the mode shapes for the first five roll bending modes. As might be expected, the shapes correspond to those of a simple cantilevered beam: the first mode has one node, the second mode has two nodes, and so on. The pitch bending modes are much the same as the roll modes.

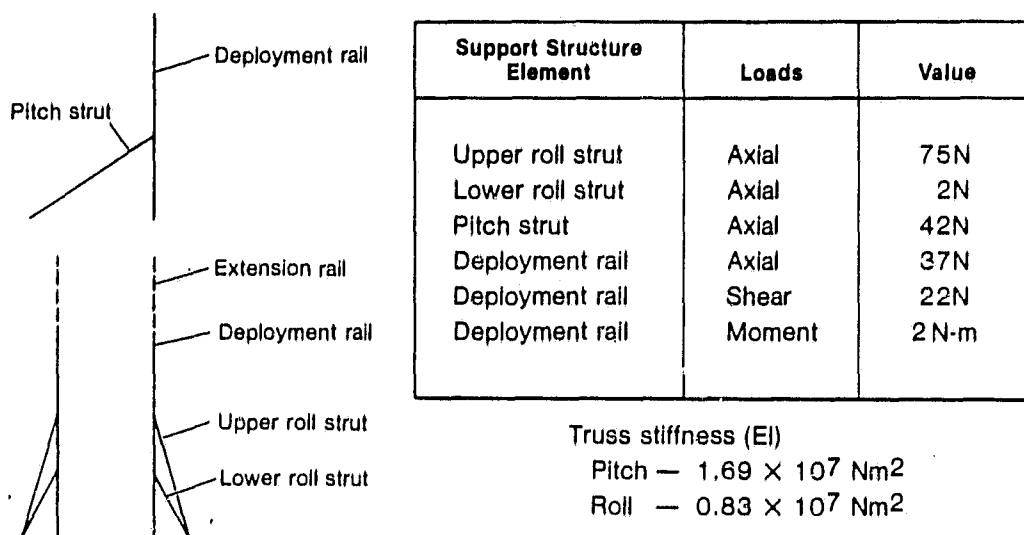
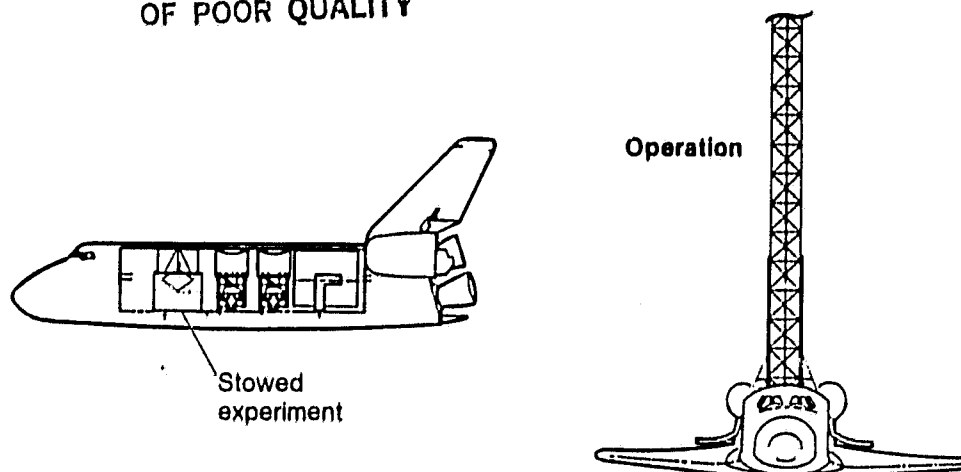


Figure 2-8. Maximum Truss Support Loads

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Item	Weight (kg)	Deployed Phase	Center of Mass (m)			Moment of Inertia (kgm ²)		
			X	Y	Z	I _{xx} (Roll)	I _{yy} (Pitch)	I _{zz} (Yaw)
Tip-mass	100	1/2	17.42	0	17.40	8.04×10 ⁴	8.04×10 ⁴	4.2×10 ²
Truss	154		17.42	0	29.39	3.53×10 ⁵	3.52×10 ⁵	4.2×10 ²
Cradle	322		17.42	0	20.39	1.47×10 ⁵	1.47×10 ⁵	4.1×10 ²
Experiments	43	Jettison tip-mass						
Total	629							

Figure 2-9. Mass Properties

Table 2-3. Flexible Mode Summary

Flexible Mode No.	Frequency Hz	Axis			
		Pitch	Roll	Torsion	Compression
1	0.190		✓		
2	0.238	✓	✓		
3	1.91		✓		
4	2.71	✓			
5	5.98		✓		
6	8.47	✓			
7	10.46				✓
8	10.68			✓	
9	12.16		✓		
10	17.18	✓	✓		
11	17.34		✓		
12	18.40				✓
13	21.0		✓		
14	26.5	✓			

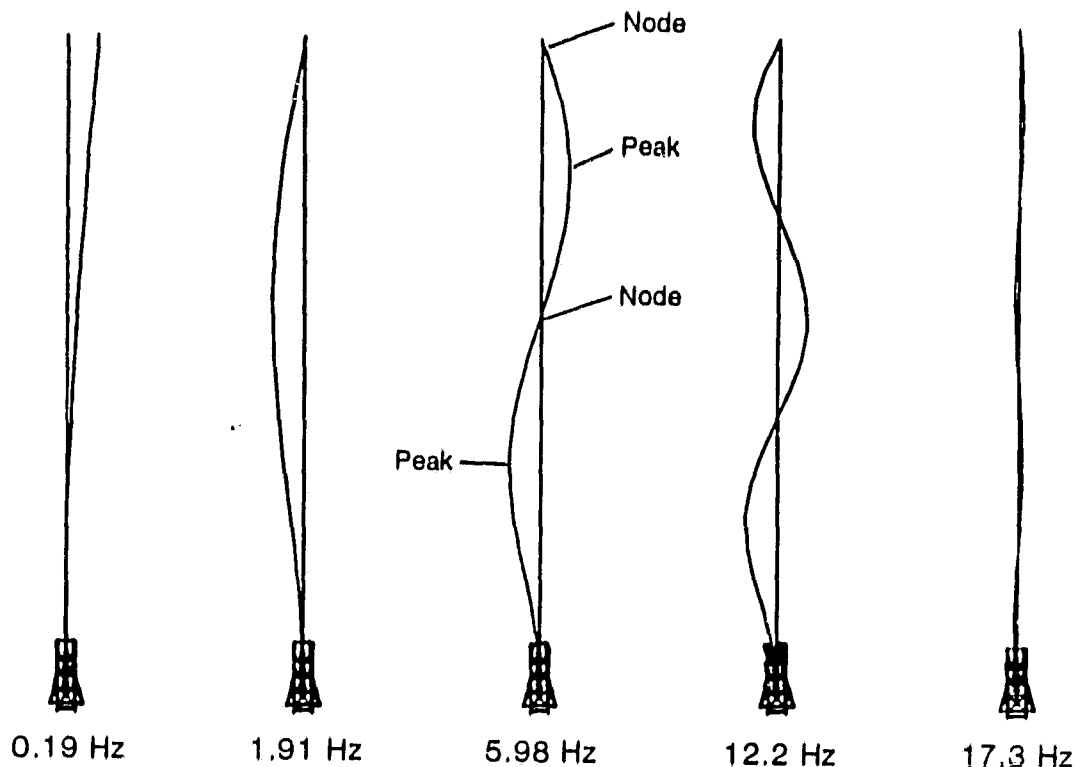


Figure 2-10. Roll Bending Mode Shapes

2.3.2 INSTRUMENTATION LOCATION. The third mode peaks and nodes have been identified in Figure 2-10. Structural testing has historically dealt with force inputs and linear (acceleration) measurements. Both the force application and the linear measurement are most effective at mode shape peaks and totally ineffective at nodes. Because force actuators have practical problems at low frequencies, the flight experiment uses torque actuators which, in turn, require slope or angular information for closed loop operation. When working with torques and slopes the situation is reversed from the force case: torques and slope sensors are most effective at nodes and ineffective at peaks.

Figure 2-11 presents a graphical presentation of the experimental structure wherein the horizontal axis at the top of the chart indicates bay location along the structure with 42 being the tip and 4 being the top of the deployment rails. Peaks and nodes are indicated for the first five pitch bending modes and sensor and actuator locations are indicated. Since the maximum slope for all modes shown is at the tip, the tip actuators can excite all of the modes. For Configuration IA and higher, there is an actuator close to at least one additional node for the third mode and above. The accelerometers are generally within one bay of the peaks and the important nodes have two accelerometers close by. Two measurements near a node permit interpolation or extrapolation to more accurately determine the exact location of the node. Two inertial grade

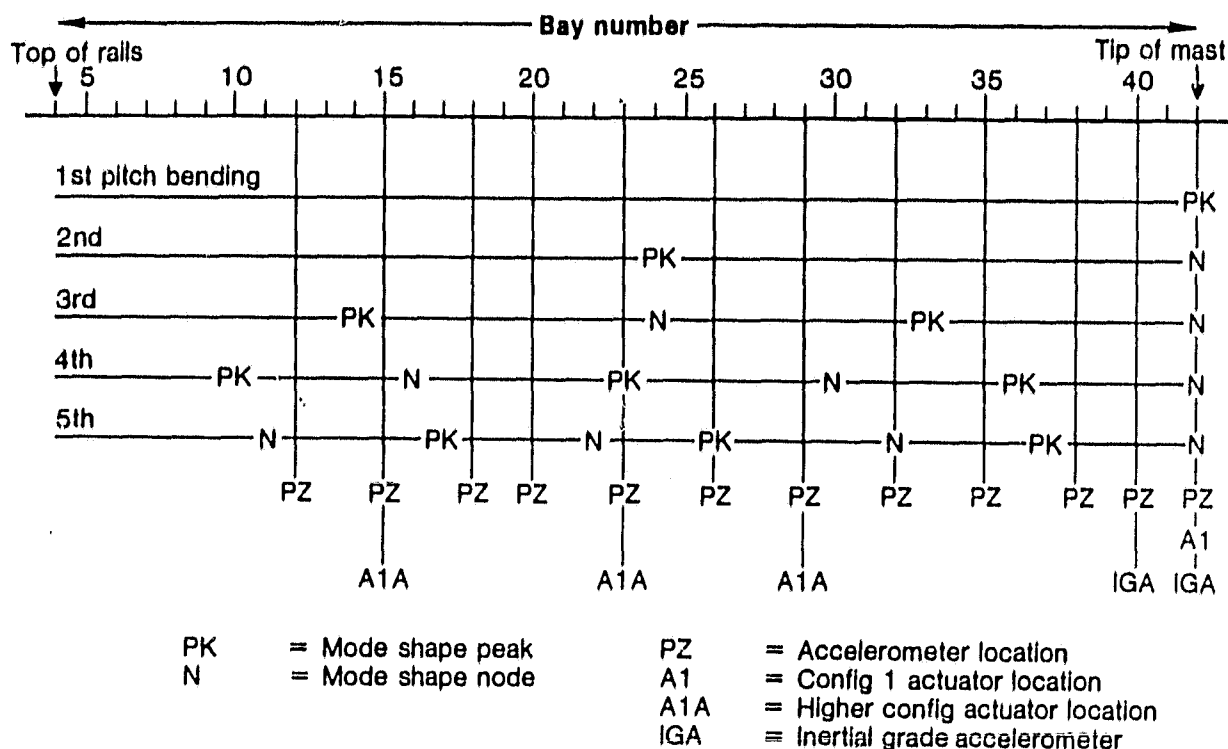


Figure 2-11. Dynamics and Control Components Location, Pitch Axis

accelerometers are used, principally for the first mode which, by virtue of its low frequency, will have significantly lower accelerations than the higher modes. Locating the components for the roll axis at the same locations as used for pitch gives excellent coverage for both axes.

Provision has also been made for monitoring loads into the Orbiter, structural loads and temperatures, tip location relative to the base, deployment carriage position, and actuator motor temperatures.

2.4 PRELIMINARY SYSTEM TEST PLAN

2.4.1 TEST PROGRAM SUMMARY. The test program flow diagram (Figure 2-12) describes an orderly progression to meet the SCE program objectives and requirements. This test program is required to assure the performance of the flight experiment hardware and to verify the technologies required to accurately predict flight test performance of the structure and the structural damping subsystem.

The material and subcomponent testing will allow system manufacturing and design problems, and math modeling uncertainties, to be evaluated and resolved during the design phase. The flight acceptance tests verify the flight worthiness, and functional capability of the SCE.

Prior to acceptance and delivery of the Space Construction Experiment and associated end items, a series of formal acceptance tests will be

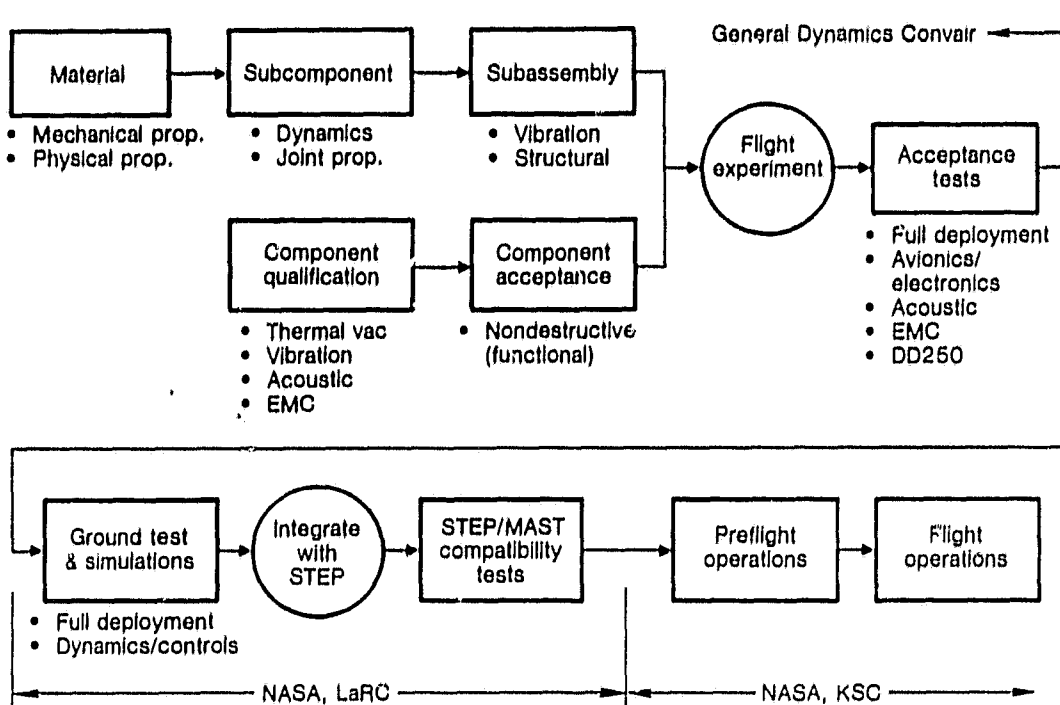


Figure 2-12. SCE Test Program Flow Diagram

conducted. These tests will be witnessed by the NASA and will culminate upon delivery of test data demonstrating performance of equipment to prescribed test specifications. The acceptance test will include, but not be limited to, a full deployment/retraction test, an acoustic test and an EMC test.

The initial structural dynamics model will derive data on struts, joints, fittings, mass properties, etc., from the component tests. The model will be tested by performing subassembly tests of the modeled 5-bay structural segment. Structural interface tests of the flight experiment support structure will allow interface deflections at the base of the truss to be computed from measured flight loads. Deployment tests and dynamics and controls tests will allow the structural dynamic and control models for the flight test article to be evaluated and provide a data base for evaluating the effectiveness of ground test of partially deployed configurations in ensuring accurate flight test performance predictions.

Following completion of the Ground Tests and Simulations the SCE will be integrated with the STEP. This will be performed at NASA, LaRC. Following physical integration power will be provided and functional testing will be conducted to verify the operating interfaces between STEP and SCE and to verify performance of the software.

Ground operations flow at KSC will be as shown in Figure 2-13. Initial preflight operations will be performed in a Payload Processing Facility (PPF) to be designated for SCE use. Payload

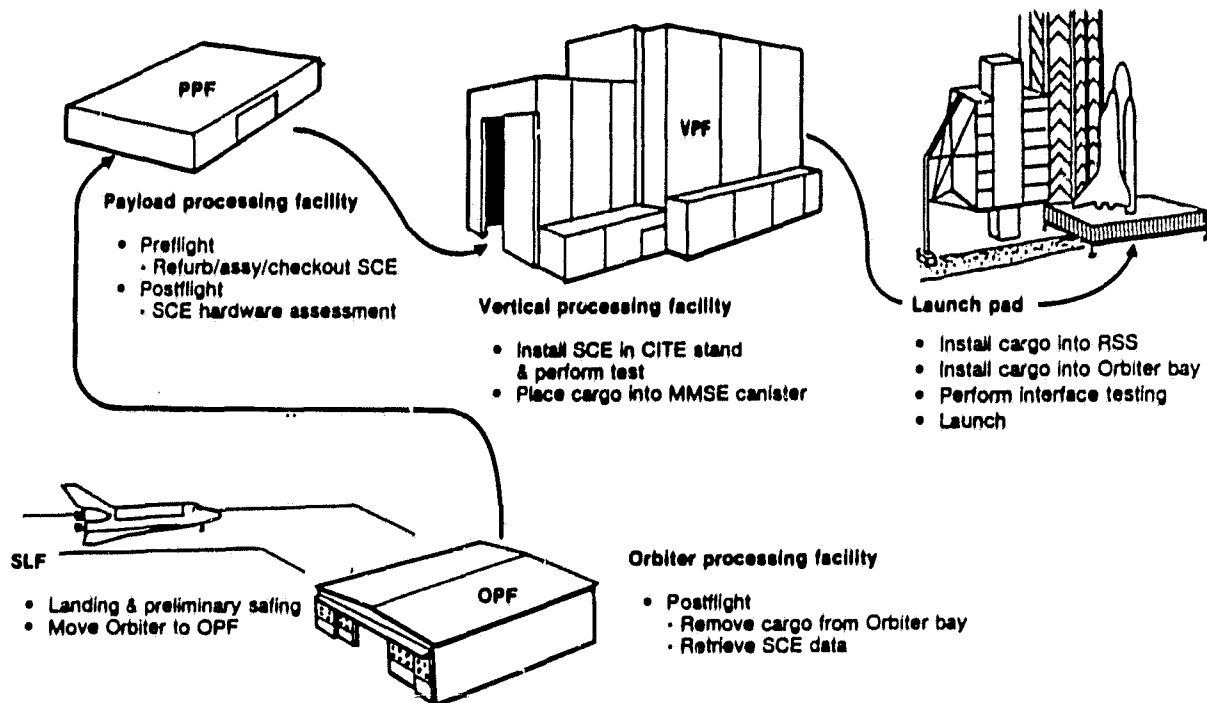


Figure 2-13. SCE Vertical Processing Operations

Processing Facility tasks include receiving and inspection, refurbishment, preparation, and checkout operations as necessary to establish SCE system flight readiness. The SCE/STEP will then be transferred to either a Vertical or Horizontal Processing Facility where it will be integrated with other assigned coflight manifested payloads (into a complete cargo assembly) and processed for launch using conventional Shuttle Orbiter preflight procedures. Either the vertical or the horizontal processing mode may be used for the SCE, permitting flexibility in its selection for compatibility with other payloads.

The flight test sequence is shown in Figure 2-14. In addition to the actual test time, significant time is required for preparation, RMS operations, and securing. The timed sequence of the actual testing is presented in Figure 2-15.

2.5 PROGRAMMATICS

2.5.1 PROGRAM DEVELOPMENT PLAN. Based on the overall program scope of the experiment a summary program development schedule has been established. The schedule (Figure 2-16) represents a nominal development approach resulting in a flight 47 months after go-ahead.

2.5.2 PROGRAM COST ESTIMATES. Refinements made to the concept selected in the first two phases of the study (including integration with STEP and resizing of the truss) provided revised input that was used in the cost analysis. Using the updated information concerning the current configuration generated in this phase of study, new

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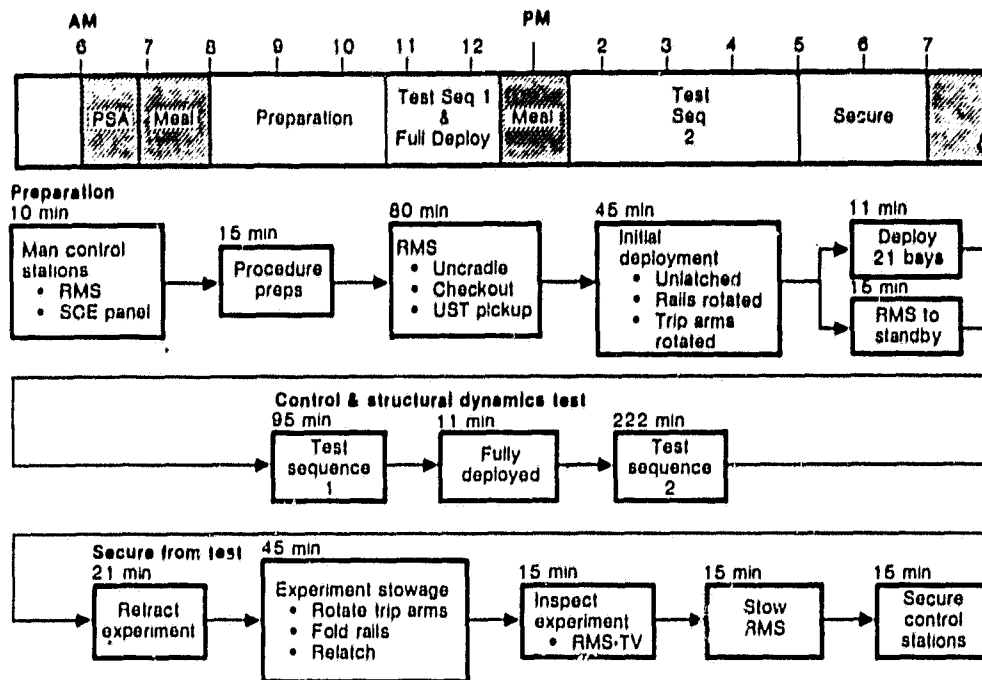


Figure 2-14. Flight Test Operations Sequence & Timelines

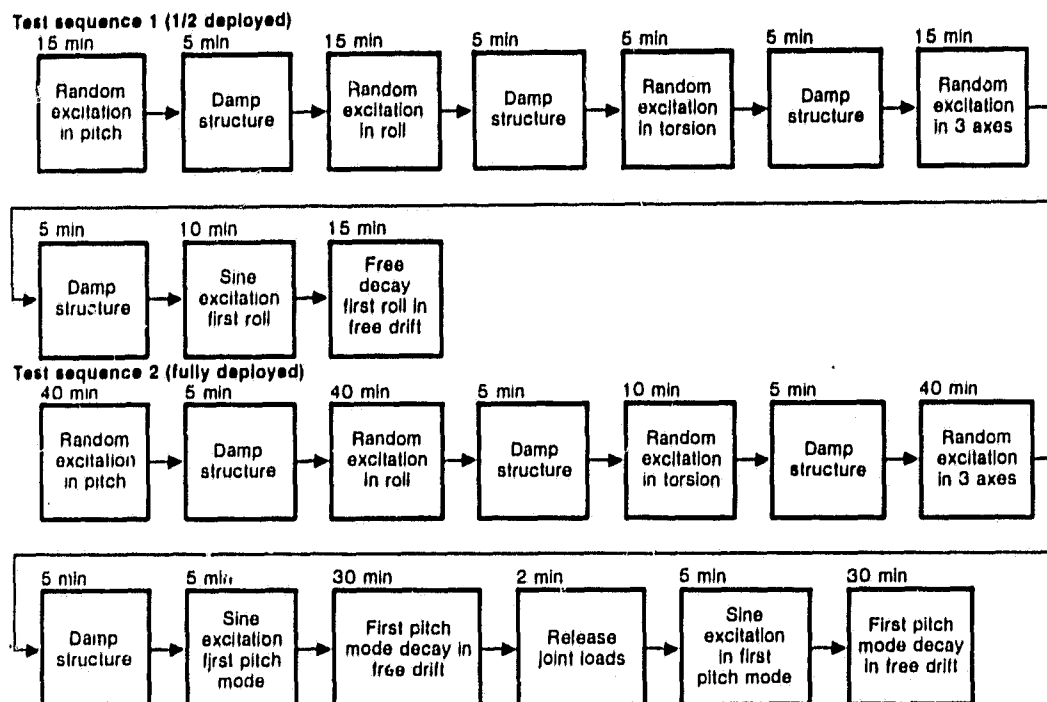
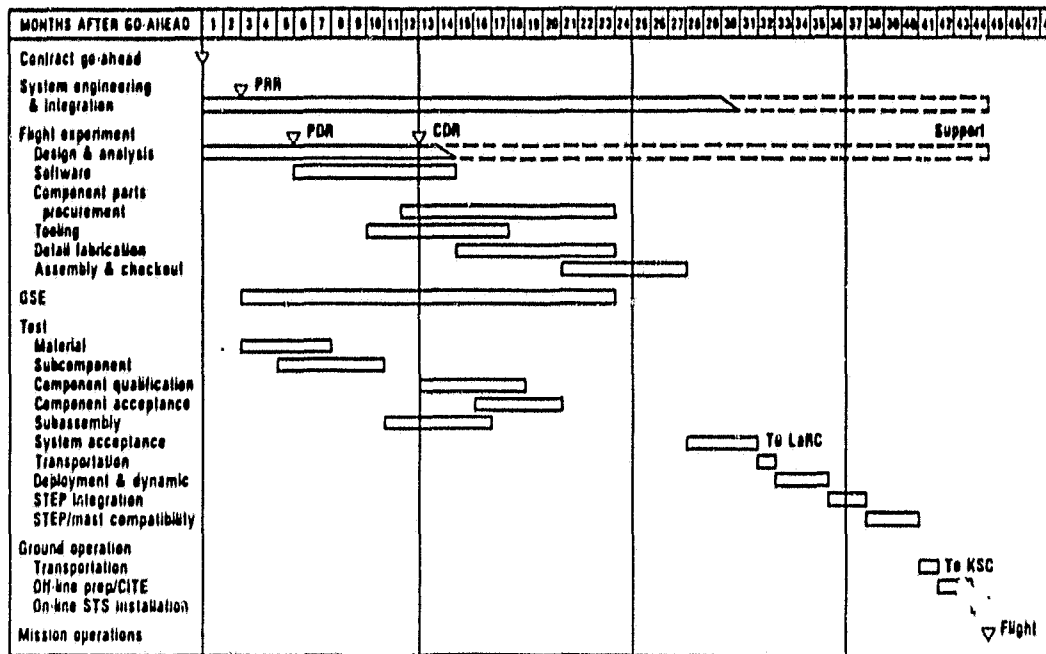


Figure 2-15. Dynamics and Controls Flight Test Sequence



cost estimates were made. The results of this cost analysis are presented in Table 2-4. The total cost for the design, development, fabrication, and test of the SCE is approximately \$11M exclusive of GFE items. The experiment flight hardware fabrication accounts for about \$3.8M and the remaining \$7.4M is required for design and analysis, component development and test, system engineering, the system level test, program, and program management.

The majority of the hardware design and development cost is required for structure and mechanisms including the truss, its deployment mechanism, and the support structure for mounting the SCE in the STEP. The dynamic test equipment is assumed to be virtually all off-the-shelf equipment such as gyros and accelerometers and very little in the way of component development and qualification will be required.

Operations costs were not estimated at this time but would consist of transportation, and ground operations for preparation for STS installation and postflight disposition plus support activities during the flight.

Annual funding requirements by years after go-ahead for development and flight article fabrication were generated by spreading individual cost elements in accordance with the program schedule (see Figure 2-17).

Table 2-4. Preliminary ROM Cost Estimates

	Design & development	Flight article fabrication
Flight hardware		
• Structure	2.33	2.45
• Dynamic test equip/instrumentation	.97	.56
• RMS equipment	.01	.01
• Airborne support equipment	.66	.16
• Assembly & integration	—	.37
Software	.14	—
System eng & integration	.76	—
System test	1.61	.10
GSE	.21	—
Spares	.32	—
Facilities	—	—
Program management	.35	.18
Total	7.36	3.83
Grand total	11.19	

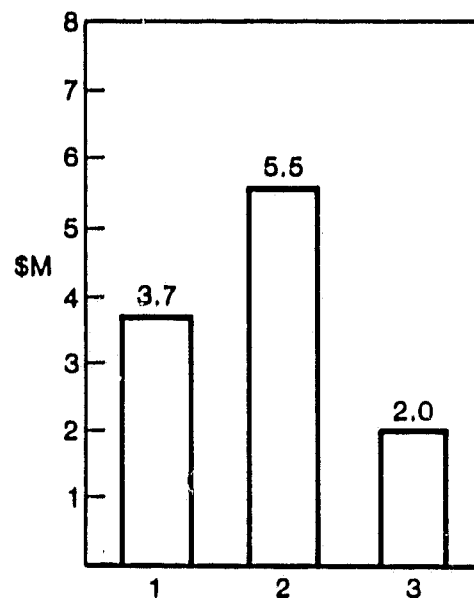


Figure 2-17. Annual Funding Requirements

SECTION 3

CONCLUSIONS AND RECOMMENDATIONS

This section presents the major conclusions and recommendations from the SCEDS Part III study effort.

3.1 CONCLUSIONS

- a. The essential controls and dynamics community needs for large space structures can be addressed by the basic SCE/MAST configuration from Part II and enhanced configurations for follow-on flights.
- b. The SCE/MAST can be integrated on a single structures Technology Experiments Platform (STEP).
- c. The experiment objectives can be accomplished without the need for EVA and it is anticipated that further design refinements will eliminate the requirement to use the RMS.
- d. Flight of the SCE/MAST is achievable 47 months after program go-ahead.
- e. Total SCE/MAST program cost, in 1983, is estimated at \$11.2 Million.

3.2 RECOMMENDATIONS

Proceed with SCE/MAST program development and as a minimum immediately commence with:

- Development of a detailed design for the truss.
- Development and evaluation of composite joints and fittings.
- Evaluation of bus cable and bus format/interconnect options for deployable truss structures.